Name: ______________________________________

LAB 4. PROJECTILE RANGE

In this activity you will clamp the launcher to a table and fire a projectile onto the floor from different initial angles. You will compare the observed trajectories to predictions from a simple ballistic model.

Supplies

Projectile launcher, projectile, ramrod, clamp, plumb line, measuring tape, meter stick, carbon paper, white paper, tape, sturdy table

Safety considerations

- The projectile launcher fires a 1-inch steel or hard plastic ball at speeds that can be considerable. To avoid eye injury, **everyone in the room must wear safety glasses or goggles while the launchers are being used**.
- **Never look down the muzzle** of the barrel. You can see into the barrel through the slots cut in the sides.
- Once the barrel is loaded, do not place any part of your body in front of the launcher.
- Use the ramrod to cock the launcher. **Never** poke your fingers into the barrel—you could very easily break them! That would be bad.
- Load the projectile launcher with 1-inch balls only. Other loads may cause dangerous conditions.

Using the projectile launcher

Description

The launcher propels the projectile using a cocked spring. The spring can be set at three positions, each with increasing exit speed and travel distance. The barrel pivots up and down to adjust the firing angle. An angle gauge with a small built-in plumb line measures the firing angle. The muzzle is the end of the barrel close to the pivot.

Care of the launcher

Do not fire the launcher without a projectile. Such a "dry fire" may damage the launcher. If you wish to release a cocked spring without firing, insert the ramrod into the barrel against the cradle and, while holding the ramrod firmly, release the trigger. Slowly pull the ramrod out of the barrel.

Do not over tighten the wing nuts; they can easily strip and break.

Setup

Place the launcher at the edge of the table with the muzzle of the barrel pointing away from the table. Clear the line of fire so that the trajectory is not obstructed.

Clamp the launcher firmly to the table. Use two clamps, one on either side of the base, if available. If only one clamp is available, put it on the side under the barrel of the launcher.

Firing

1. Place the projectile into the muzzle of the launcher. Push it into the barrel using the ramrod. As you push it in, the trigger on the top of the barrel will rise and fall with a click up to three times. After each click, the launcher is cocked in that position. **Use two clicks**.
2. If the barrel is horizontal, check that the projectile is against the cradle by looking through the slots in the side of the barrel. If the projectile has rolled forward, gently push it back against the cradle with the ramrod.
3. Check that no one is in the line of fire.
4. Announce intention to fire with a countdown from "3."
5. After calling "1," fire the launcher by pulling up on the trigger.
6. Watch the projectile as it travels and bounces so that you can retrieve it.

Lab activities and measurements

Data sheet

Enter your measurements into your data sheet.

Activity 1. Finding launch speed

In this activity, you will fire five shots horizontally off the table onto the floor and measure the distance traveled. Assuming the projectiles accelerate downward with magnitude g, you will calculate how long they were in the air, and thus how fast they were moved horizontally.

1. Adjust the barrel to fire horizontally (0°).
2. Using the plumb line, find the point on the floor directly beneath the muzzle. Mark this point with tape.
3. Measure the height of the muzzle above the floor. Record the height in your data sheet.
4. Load, cock, and fire the launcher. Note where the projectile lands.
5. Tape a piece of white paper onto the floor where you saw the projectile land. Place a piece of carbon paper, carbon side down, atop it. Place another piece of white paper atop the carbon paper to protect it from tearing.
6. Check that the launch angle is still horizontal. Adjust if not.
7. Load, cock, and fire the launcher.
8. The projectile should have landed on the paper and made a mark on the white paper on the floor. Leaving this paper taped to the floor, find the mark and label it.
9. Replace the carbon paper and protective sheet.
10. Repeat steps 6–9 for a total of five shots onto the paper.
11. Measure the distances from the point on the floor beneath the muzzle to the marks on the paper. Record these distances on your data sheet.

Activity 2. Range

In this activity, you will launch the projectile five times each at angles of 10°, 20°, 30°, 40°, 50°, and 60° to find how range (horizontal travel distance before landing) varies in response to launch angle. You will then try two more launch angles to get closer to the angle giving the longest range.

1. Set the launch angle to the desired value.
2. Fire the launcher to see where the projectile lands. Record the landing position of five shots as before, checking that the barrel is at the proper angle before each shot. Repeat for all specified angles.
3. Choose two additional launch angles to try to find the maximum range. Fire five shots from each angle and record the distances on your data sheet.

Processing, Analysis, and Interpretation

You will find how well your measurements correspond to a simple ballistic model of the system. Assume that the launcher fires the projectile at the same speed for every launch angle, and that the projectile in flight is subject only to the force of gravity. First, using the data from the horizontal launches, you will deduce the muzzle speed of the projectile. You will then use that muzzle speed to predict the range of the projectile at different launch angles, and compare these predictions to your observations.

You will want a spreadsheet to process and analyze your data. You may use Google Sheets.

Activity 1. Finding projectile speed

Drop time

1. Enter the muzzle height into your spreadsheet.
2. Enter formula 1b, which calculates the drop time for the horizontally fired projectiles, into your spreadsheet. Incorporate the muzzle height into the formula by reference.

Launch speed

1. Enter the measured projectile ranges x from the horizontal launches (Activity 1) into the spreadsheet.
2. Calculate $\bar{x}$, the mean value of the projectile range (horizontal distance), incorporating the measurements by reference. (Sheets has an AVERAGE function.)
3. Enter formula 2b, which calculates v_{0x}, in the spreadsheet. Incorporate the calculated value of $\bar{x}$ by reference. Because the launches were horizontal in this activity, this is also your estimate of v_0.

Activity 2. Measured range

1. Enter the launch data into your spreadsheet. Organize it as a matrix, with a row for each angle and a column for each range.
2. Add a column for the mean ranges. Calculate the mean range for each launch angle.

Predicted ranges

1. Below the data matrix, fill the angle column with angles from 0 to 65, with each row incremented from the previous row by 1.
2. In the next column, convert the degrees to radians. ($180° = \pi$ radians. Sheets has a PI() function and also a RADIANS function.)

3. In the next two columns, calculate v_{0x} and v_{0y} for the angles. Use your estimate of v_0 by reference.
4. In the next column, calculate the time t that the projectile should be in the air. Use the formula 3c. Incorporate the values of h and v_{0y} by reference.
5. In the next column, calculate the expected range x for each projectile. Use formula 3d. Incorporate the values of t and v_{0x} by reference.

Plot

Make a plot of range x as a function of launch angle α, containing two different curves: your calculations for angles 0°–65°, and the averages from the experimental angles. The experimental ranges should be shown as plot symbols with no line connecting them. The calculations would be best shown as a smooth curve without plot symbols, but if you can't figure out how to do that on the same plot with the bare plot symbols (I can't), show them as smaller plot symbols. Both x columns (experimental and calculated range) should use the same α column. Make sure that the plot, the axes, and the two sets of x values are clearly labeled.

Analysis

Do the measured and calculated ranges match reasonably well? If not, first check to see if you have made an error in a formula, calculation, or measurement. If you find errors, fix them. If you don't find errors, see me for help. If, after all this, the measured and calculated ranges still do not match, try to figure out what is wrong.

If the measured and calculated ranges match, estimate the angle α giving the longest range.

Lab Report

Data: Turn in your completed **data sheet**.

Processing: Each student should make an individual, personal spreadsheet. If it's a Sheets spreadsheet, share it with me. If it's an Excel sheet, upload it to Canvas. It should be set up clearly and organized logically. Appropriate column headings and labels should lead me to the data, the intermediate calculations such as v_0, and the results.

Results: The spreadsheet should include your **plot** of predicted and measured x vs. α.

Analysis: Comment on the match between the measured and predicted ranges. What does the match, or lack thereof, indicate about the model and the data? Tell me your estimate of the angle α giving the longest projectile range.

Name: ____

LAB 4 FORMULAS

1. Imagine a projectile in free fall from rest at an initial height h.
   a. Find the kinematic equation for the height y as a function of h, g, and time t. For simplicity, make the ground's height equal to zero.

      $y =$

   b. Solve the equation for time to land on the ground (find t when $y = 0$).

      $t =$

2. The horizontal component of velocity v_x of any projectile affected only by gravity is constant.
   a. Find the kinematic equation for x, the horizontal component of its position, at time t.

      $x =$

   b. Solve the equation above for v_x in terms of x and t.

      $v_x =$

3. Imagine a projectile launched with speed v_0 at angle α above horizontal from a height h.
   a. Find the formulas for v_{0x}, the horizontal component of initial velocity, and v_{0y}, the vertical component of initial velocity, in terms of v_0 and α.

      $v_{0x} =$ $v_{0y} =$

   b. Find the formula for height y as a function of g, h, v_{0y}, and t.

      $y =$

   c. Solve the equation for time to land (find t when $y = 0$).

      $t =$

   d. Find the formula for horizontal travel distance x as a function of v_{0x} and t.

      $x =$

Name: ____

Projectile Launch Data

Muzzle height h = _______________

Launch angle	Distance					
α	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
0°						
10°						
20°						
30°						
40°						
50°						
60°						

Notes: